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A6_1 Zap!.. and the Poles Are Gone!

D. Nutting, S. Mucesh, D. Watters and M. N. Chowdhury

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

We consider using the most powerful laser available to terraform Mars by sublimation of polar dry ice. The increase in atmospheric concentration of CO_2 results in a surface temperature increase of 2.7 × 10^{-5}K.

Introduction

August 8^{th} 2016, also known as the "Overshoot Day", marked the point at which humanity began consuming more resources than the Earth could regenerate naturally [1]. With the growing population and the increasing energy demand, the idea of colonising space in the near future will become a necessity. Due to its close proximity and the many similarities it shares with our home planet, Mars stands out as the most obvious candidate to establish a colony on. However a major hurdle is the extremely cold surface temperature of 218K [2]. We researched the possibility of raising the surface temperature by sublimating the dry ice (CO_2) present at the Martian poles using the most powerful laser currently available.

Theory

Both polar caps are composed primarily of water ice with a thin layer of dry ice covering the top [3]. The mass of dry ice present at the north pole, $M_n = 1.3 \times 10^{15}$kg, was calculated using the thickness of dry ice, $d_n = 1$m, the radius, $r_n = 500$km [4], and its density, $\rho = 1600$ kgm^{-3} [5] as:

$$M_n = \pi r_n^2 d_n \rho \quad (1)$$

Consequently the energy required to completely sublimate any dry ice, Q_n, can be calculated as:

$$Q_n = M_n c \Delta T + L_s M_n \quad (2)$$

where $c = 0.709$ kJkg^{-1}K^{-1} [6] is the specific heat capacity of dry ice at 175K, $\Delta T = 74.5$K [2] is the temperature difference between the minimum annual surface temperature at the poles (120.15 K), and the sublimation point of CO_2 (194.65 K) and $L_s = 571$ kJkg^{-1} [5] is the latent heat of sublimation. This process is also used to get the energy required to sublimate the southern pole, Q_s, using $d_\mathrm{s} = 8m$ and $r_s = 175$km [4], giving a CO_2 mass of $M_s = 1.2 \times 10^{15}$kg.

The sublimation of the poles' dry ice could lead to a significant increase in the concentration of CO_2 within the atmosphere, resulting in the increase of the surface temperature due to a stronger greenhouse effect.

This influx of CO_2 will increase its radiative forcing, ΔF, which is the difference between the energy absorbed and radiated by Mars [8]. The change in surface temperature, ΔT_{surf}, can be found via:

$$\Delta T_{surf} = \lambda \Delta F \quad (3)$$

where λ has a value of 0.8 Km^{2}W^{-1} [8]. ΔF (Wm

$^{-2}$) can be found using:

$$\Delta F = 5.35 ln(\frac{C}{C_0}), \quad (4)$$

where C_0 and C are the CO_2 concentrations in parts per million by volume (ppmv) in the atmosphere before and after sublimation respectively. The Martian atmosphere is composed of 95.97% CO_2. The percentage volume of CO_2 in the atmosphere gives the initial concentration as $C_0 = 959700$ppmv, while the final concentration is found via:

$$C = \frac{0.96V + V_a}{V + V_a} \quad (5)$$

where $V_a = M_T/\rho_{co_2}$ is the volume of CO_2 added to the atmosphere, $\rho_{\mathrm{CO_2}}$ is the density of CO_2 (1.977 kgm^{-3}), $V = 9 \times 10^{18}$ m^3 [7] is the volume of the atmosphere and $M_\mathrm{T} = M_\mathrm{n} + M_\mathrm{s}$ is the total mass sublimated from both poles.

Results

The final CO_2 concentration has a value of $C =$ 950006ppmv. The total energy required to sublimate both poles is $Q = Q_\mathrm{n} + Q_\mathrm{s} = 1.6$ x 10^{21}J where $Q_n = 8.1 \times 10^{20}$J and $Q_s = 7.5 \times 10^{20}$J. The LFEX laser is currently the most powerful laser in the world with a peak output power of 2PW, delivering 150-200J in one picosecond [9]. In optimal conditions such as complete absorption, a laser would be able to sublimate both CO_2 reservoirs in ∼9 days with a continual output. Using Equation 3 we found that a CO_2 input of 1.3 x 10^{15}kg into the atmosphere would lead to a surface temperature increase of 2.7 x 10^{-5}K.

Discussion

The energy required to sublimate the poles is beyond human capabilities; this value is an underestimate due to simplified assumptions. The temperature change calculated is unrealistic as we have ignored re-condensation of CO_2 and atmospheric stripping due to solar wind. Another consideration is the evaporation of water ice which is 1000 times more abundant than dry ice. Evaporation of this would release a large amount water vapour into the atmosphere. Water vapour acts as a greenhouse gas and drives climate change much in the same way as CO_2. The only difficulty in achieving such a feat is the length of time required, which is calculated to be ∼1700 years.

Conclusion

The prospect of using the LFEX laser for terraforming Mars is not feasible. The power required, and the technological limitations of producing a continuously firing 2PW laser, prevents this technique from being practical.

References

[1] http://www.overshootday.org/ accessed on 05/10/2016

[2] https://en.wikipedia.org/wiki/Climate_of_Mars accessed on 05/10/2016

[3] http://www.nasa.gov/content/dry-ice-moves-on-mars accessed on 05/10/2016

[4] https://en.wikipedia.org/wiki/Martian_polar_ice_caps accessed on 05/10/2016

[5] https://en.wikipedia.org/wiki/Dry_ice accessed on 05/10/2016

[6] http://www.engineeringtoolbox.com/carbon-dioxide-d_974.html accessed on 05/10/2016

[7] W. H. A. Longman, K. Flatt, S. Turnpenney, M. Garreffa, *A1_9 Terraforming Mars: CO2 Combustion*, PST 13, (2014).

[8] https://en.wikipedia.org/wiki/Radiative_forcing accessed on 04/10/2016

[9] goo.gl/T8HBVK accessed on 04/10/2016